LOCAL AREA AUGMENTATION SYSTEM (LAAS) UPDATE

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ABSTRACT

The Federal Aviation Administration (FAA) is developing the Local Area Augmentation System (LAAS) as a public use Ground-Based Augmentation System (GBAS). The LAAS is required to support all categories of precision approach navigation. The purpose of this paper is to summarize the LAAS technical activities and program plans. First, the complementary roles of the Wide Area Augmentation System (WAAS) and LAAS are summarized. Then technical activities are discussed, including requirements, system architecture, and flight tests. The paper concludes with a summary of recent activities and the FAA's plans for LAAS.

1. INTRODUCTION

1.1 Background and Overview

The US Federal Aviation Administration's (FAA) Local Area Augmentation System (LAAS) program is the second of two formal development initiatives aimed at augmenting the Global Positioning System (GPS) Standard Positioning Service (SPS) for civil aviation use. The first of these activities, the Wide Area Augmentation System (WAAS), is a Space-Based Augmentation System (SBAS) that augments SPS by providing improved required navigation performance (RNP) in accuracy, integrity, continuity of service, and availability. WAAS provides great efficiency with respect to minimizing the required number of ground facilities in providing continental coverage. For precision approach, it makes use of a differential technique that provides separate corrections for satellite clock error, ephemeris error and ionospheric delay based on observations from a minimally-distributed network of reference stations. The corrections are broadcast via special transponder payloads on geostationary communications satellites in the form of digital data contained in GPS-like signals. The WAAS will satisfy RNP for sole means use in oceanic airspace, US domestic airspace, US terminal areas, non-precision approach, and Category I precision instrument approach. WAAS should prove enormously beneficial to both the FAA (as a navigation service provider) and to users of US airspace alike. It will enable the FAA to eventually decommission a vast inventory of terrestrial navigation aids (VOR, DME, etc.) at significant savings in operations and maintenance cost while serving as a critical enabling technology for "free flight," a concept for the more efficient and flexible use of US airspace.

The LAAS is intended to complement WAAS service. LAAS uses a differential technique of a single correction that accounts for all expected common errors between a local reference and users. Hence, LAAS will broadcast navigation information in a "localized" service volume of approximately 30 nmi. This service volume would typically encompass a specific airport or airports within close proximity. Although the service volume of LAAS is much smaller than WAAS, the local area nature of LAAS is an advantage in terms of providing greater accuracy than WAAS. LAAS should, therefore, be able to provide precision-approach service beyond the capability of WAAS and shorter integrity response time. This will include all Category I precision approach requirements (higher availability than WAAS), Category II instrument approach, and Category III instrument approach and landing. Additionally, the quality of the LAAS signal-in-space should provide new services, for example, airport surface navigation and sensor for automatic dependent surveillance (ADS) in low visibility. The LAAS architecture will permit inclusion of other GNSS elements (e.g., Global Navigation Satellite System (GLONASS)). LAAS will operate independently of WAAS while being fully compatible with it. This will enable LAAS to provide a satellite-based, independent backup to WAAS service within the US.

1.2 Scope of the LAAS Program

The FAA's LAAS activities are based on several precursors. First of all, the FAA completed a very successful Category III feasibility study in 1995 that demonstrated that local area differential GPS was capable of supporting automatic approach and landing. The FAA sponsored over 400 successful automatic approaches and landings. Several alternative methods for integrity monitoring were evaluated [1]. This program demonstrated that a GBAS can meet the requirements of [2]. During feasibility testing, the FAA began to develop a LAAS Operational Requirements Document (ORD). This document is another key step in taking a system concept from R&D to reality. A discussion of LAAS requirements is given later in the paper. Simultaneously, US industry and the FAA developed a Minimum Aviation System Performance Standard (MASPS) for local area differential GPS (LADGPS) Category I precision approach [3]. Although this standard was intended for "Special" CAT I (i.e., private) use, industry research and development have furthered the application of differential technology. In fact, there have been some changes to the MASPS to reflect this research. Finally, the FAA studied the life-cycle-costs of LAAS to analyze costs and benefits. This initial study revealed that LAAS is cost justified for use in the US at major airports, since one LAAS ground configuration can provide precision approach for all runway ends on an airport.

The decision to fund development and acquisition of LAAS is still pending, contingent upon budget priorities and additional investment analysis. Nonetheless, system definition, specification, and prototyping will go forward in the next five years. FAA plans call for completion of a LAAS specification for all ground-based equipment and software by the end of 1998. Minimum Operational Performance Standards (MOPS) for user equipment will also be completed by that time. At the same time, system requirements will be finalized, as will system architecture.

1.3 Outline

This paper first reviews the LAAS architecture considerations and operational performance requirements. Then the technical activities and issues are discussed. These activities include requirements, system design, a schedule of major activities, and future test programs. A summary of past program activities, including the Category IIIb feasibility program, can be found in [1].

2. THE DIRECTION OF THE LAAS SYSTEM DESIGN

The LAAS architecture considerations together with system performance requirements serve as the basis for LAAS architecture choices and the basis for evaluation of LAAS system performance. The considerations and performance requirements are discussed in turn.

2.1 LAAS Architecture Considerations

FAA definition of LAAS is predicated on several key considerations. The considerations are intended to produce a system that meets all requirements, allows room for growth, simplifies the certification process, and minimizes costs to the service provider and users. LAAS program considerations are as follows:

1. LAAS will be an "ILS look-alike". This assumption has profound implications. It not only means that cockpit instrument scaling and procedures will emulate ILS; it also means that the service provider will have primary responsibility for integrity (safety) of the signal-in-space.
2. Provide an evolutionary path from Special Category I (SCAT-I) [3] to ease the transition burden.
3. Incorporate multiple ground reference stations for averaging corrections and integrity monitoring.
4. As necessary, to increase system availability, incorporate additional "lines-of-position" through means other than the satellites themselves (e.g., pseudolites).
5. Ground equipment will be centralized and installed on airport property.
6. Minimization of the need for excessive reference-station antenna separations and clear areas.
7. Data broadcast in existing navigation bands.
8. Ground systems will be modular in design to accommodate CAT I through CAT III.
9. Ground systems will be interoperable with each other (CAT I through CAT III), and interoperable with WAAS, but independent of WAAS.
10. Additional aircraft equipment (e.g., antennas) will be kept to a minimum in order to minimize costs.
11. Based upon GPS SPS, but will allow growth for other global navigation satellite systems (GNSS) elements (e.g., GLONASS).
12. Not be dependent upon use of aircraft inertial systems, and will not be dependent upon on-board radio altimetry although its use is implicit within CAT III requirements.

The above list was a practical starting point for the FAA's determination of a LAAS architecture and the system standards necessary for LAAS realization.

2.2 Performance Requirements

LAAS performance requirements are evolving. The FAA has completed an ORD for LAAS [4]. This ORD is available for public comment. It is presently undergoing review both within the FAA and the aviation community. The performance requirements focus on the RNP parameters of accuracy, integrity, continuity, and availability. Table 1 summarizes these performance requirements as a function

Table 1. Summary of Assumed LAAS Performance Requirements [5]

Requirement	Category I	Category II	Category III
Vertical Position Accuracy*	4.0 m	2.5 m	2.5 m
Integrity	4×10^{-8} / approach	4×10^{-8} / approach	1×10^{-9} / approach
Time-to-alert	6 s	2 s	2 s
Vertical Alert Limit	10 m	5 m	5 m
Continuity	1×10^{-5} / approach	1×10^{-5} / approach	1×10^{-7} / 30 s

* For integrity, actual vertical position accuracy will be greater (0.6–1.0 m)

of the category of approach and includes the latest proposed modifications of the original ORD requirements [5].

Accuracy. The position accuracy requirements in the above table are given in terms of the navigation sensor error (NSE), and are sufficient for automatic landing guidance. NSE encompasses:

- The signal-in-space errors (e.g., errors in the differential data and any satellite signal errors that may not be removed in the differential data)

plus

- Errors local to the aircraft (e.g., receiver noise and multipath errors at the aircraft antenna).

Integrity. The integrity of the DGPS data must meet the requirement of the probability of hazardously misleading information (HMI), which is reflected in the integrity requirements. The probability of HMI drives fault-tree probability requirements of the ground station and the alert limits that are guaranteed for obstacle avoidance and path following. It should be noted that the accuracy requirements for integrity availability are more stringent than that for position accuracy needed to perform successful automatic landings. Therefore, the LAAS accuracy will be significantly better than that displayed in the first row of Table 1. It will be 0.6 - 1.0 m.

Continuity. Loss of continuity encompasses both disruption of the DGPS broadcast data and the satellite signals. It is connected to integrity through the alarm threshold setting on the integrity monitoring of the DGPS data. The lower the alarm threshold, the higher the probability of rejecting a satellite for navigation.

Availability. Availability encompasses meeting the other three performance requirements simultaneously. Therefore, it accounts for those outages of the ground and space segments caused by equipment failure and satellite geometry. The LAAS availability analysis considers outage duration, as well as outage and restoration rates. There is a range of values for availability to match individual airport requirements. The nominal availability requirement is 0.999.

2.3 Selection of Carrier-Smoothed Code

Since the carrier-smoothed code (CSC) technique for the navigation solution is less complicated than the carrier phase (CP) technique, apparently meets the Category I and II requirements, and accommodates SCAT-I, CSC was selected for these two categories.

The Category III feasibility program showed that CSC can provide consistent guidance to an older-generation autopilot in the autoland of a B-727 aircraft within the touchdown box [6] as well as a newer generation airplane (Boeing 757) [7], comfortably meet the Category II accuracy requirements, and CP had shortcomings with respect to LAAS guidelines. Thus, only CSC is being considered for LAAS.

2.4 LAAS System Architecture

The FAA has selected Ohio University and Stanford University to provide designs and flight-testable prototypes that have the potential to meet the LAAS architecture guidelines and performance requirements. Their work is reviewed and synthesized by the LAAS Architecture Review Committee (LARC). Based on the work of the universities and as developed by the LARC, [5] contains a detailed review of the FAA's initially proposed (prior to harmonization within RTCA in December 1996) LAAS architecture. After harmonization with RTCA, the major features of the LAAS are:

1. Carrier-smoothed differential code corrections and carrier measurement corrections are broadcast to aircraft where the data are used to produce carrier-smoothed code position solutions.
2. Prior to broadcast, the initial integrity monitoring of the correction data is accomplished by comparisons of the corrections from the different reference receivers, based on a statistical approach similar to [8]. The avionics is only responsible for:

- Computing the vertical and horizontal position protection levels using standard equations whose parameters are error data from the ground and representations of required continuity and integrity probabilities
- Comparing the position protection levels to their respective alert thresholds. This method has been called "range-domain integrity" because the primary integrity monitoring and screening of the signal-in-space is accomplished in the range domain.

3. The differential corrections are based on averages from at least two ground reference receivers to enhance accuracy and limit any large non-common errors.
4. Since multipath is the dominant error in local DGPS, a specially designed multipath-limiting antenna is being developed for LAAS reference stations. Other multipath limiting techniques that use signal processing are being considered.
5. The number of reference stations increases with respect to the category of approach. It is expected that Category I will require 2, Category II will require 3 and Category III will require 4 reference stations with antennas sufficiently separated to decorrelate multipath.
6. Pseudolites (ground-based transmitters of GPS-like signals) will be selectively used at airports to provide additional signals to meet availability requirements.
7. Signal-quality monitoring (SQM) will be used to monitor critical signal parameters, such as code correlation functions as well as the signal levels. The monitoring of critical signal parameters is characteristic of existing navigation aides (e.g., ILS and VOR).

   Figure 1 contains a schematic depiction of the LAAS architecture.

3. FAA FLIGHT TEST PROGRAMS

A LAAS Test Prototype (LTP) has been established by the FAA LAAS Program Office (AND-730) in order to facilitate the determination and validation of the LAAS system architecture. This engineering prototype is located at the William J. Hughes Technical Center. The current LTP is a GBAS which is based on a system developed by Ohio University as part of the FAA's CAT III Feasibility Program. The LTP was recently flight tested in the United States at Atlantic City, New Jersey, Savannah, Georgia, and Bellingham, Washington, and also in Canada at North Bay, Ontario. Results to date have shown that the system performs at about a 1.2 m 95 percent vertical error, consistent with past Ohio University tests. LTP flight tests, which are ongoing, are an independent evaluation of FAA sponsored work performed by participating universities. The LTP will evolve with the FAA LAAS, and will be used to quickly implement and evaluate LAAS system improvements.

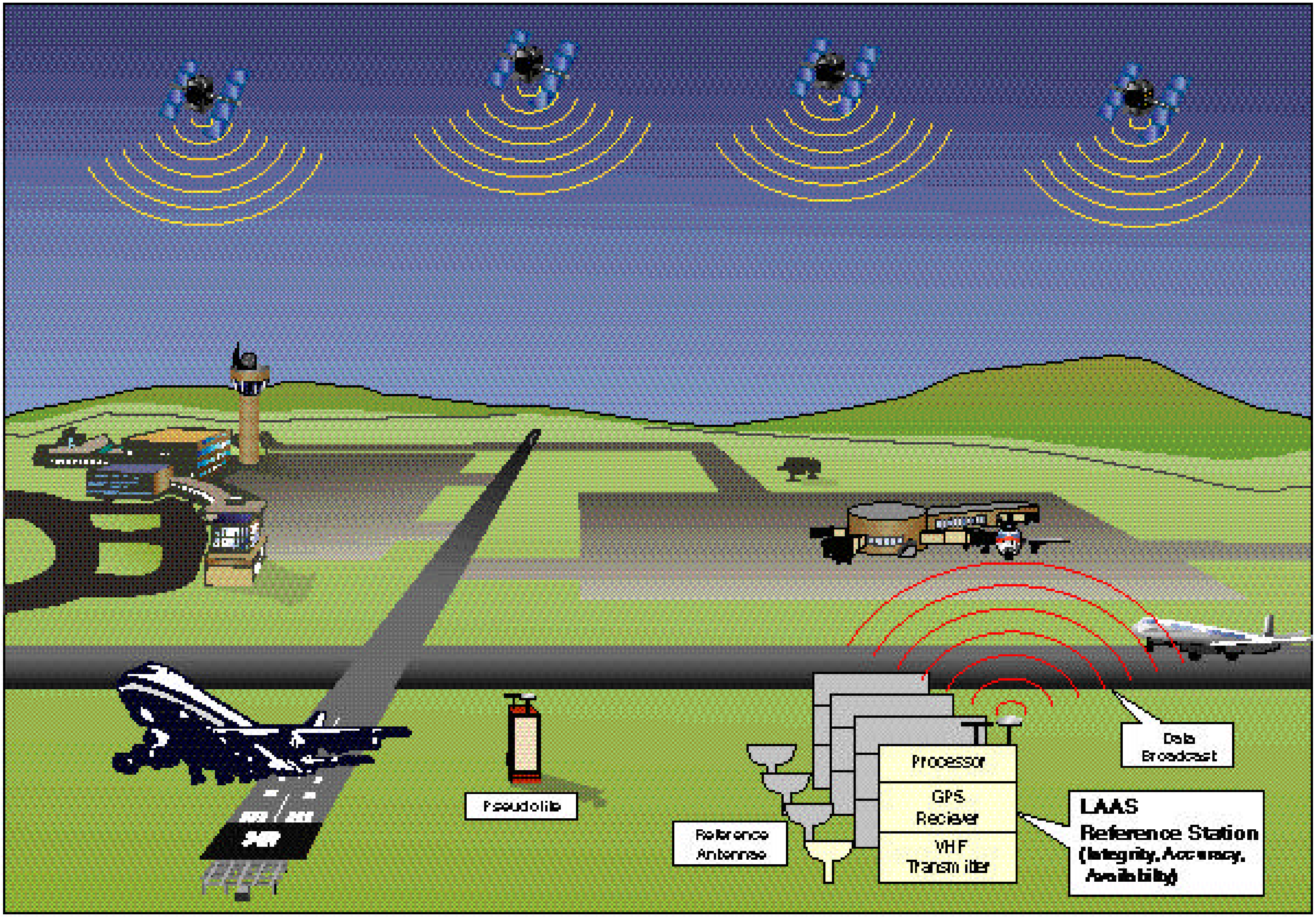

Figure 1. LAAS Architecture Schematic

Figure 2 [9] illustrates how airport pseudolites (APLs) enhance GBAS availability. The FAA recently took delivery of three standalone APLs to be used in FAA research programs. These generic test tools transmit GPS-like signals; however, the signals are modified to mitigate interference with reception of the GPS constellation. The current APL can be set in several pulsing modes, including RTCM-104, with varying duty cycles, and can also operate on several frequencies, including GPS L1. One APL was used during the LTP flight tests in the US described above. The flight test data will be used to define required APL transmit power levels, siting requirements, and the optimum pulse format. Currently APL ranging data is being collected for post-flight analysis to better characterize APL performance and its effective incorporation into the LAAS navigation solution.

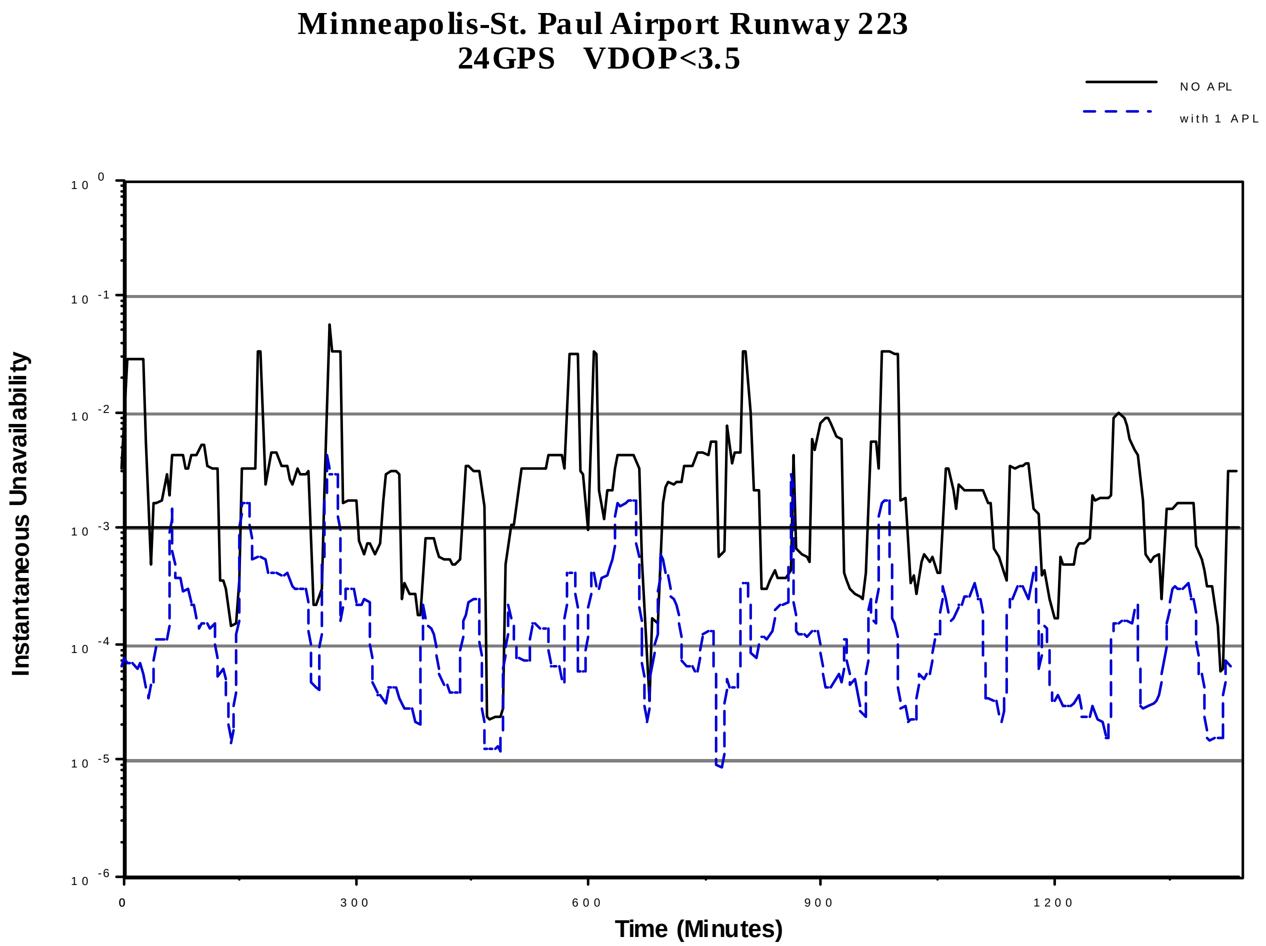

Figure 2. Effectiveness of Airport Pseudolites (APLs) in Enhancing Availability (Average Availability Without APL = 0.9954; with APL = 0.99975)

Ohio University has been actively involved in LAAS architecture design and will incorporate the best available techniques recognized by government and industry. A key element to this design is the use of the multipath limiting antenna (MLA) which was designed by Ohio University researchers. Their upcoming flight test campaign will demonstrate the improvement in accuracy through the MLA, and help to ensure that the vertical protection limit (VPL) and horizontal protection limit (HPL) are on the order required for Category III operations. The second key element is the integrity algorithms that OU will develop. They will incorporate a range-domain method of integrity that is like the one being selected by RTCA.

Ohio University researchers have also developed an APL which is offset from L1 at +8 MHz. This technique can pulse at a slower duty cycle, proposed to be 1/3, at a high enough power to ensure reception by top-mount aircraft antennas, and avoid adding additional antennas to the under side of an aircraft. This is obviously an important economic consideration from an airframe manufacture and airline point of view, who want to minimize the number of antennas where possible. Another important reason to avoid a bottom mount pseudolite antenna is the susceptibility to ground interference sources such as Mobile Satellite System (MSS) users.

Stanford University researchers have proposed another possible use of APLs. The concept would take advantage of precise carrier phase information from APLs. Stanford refers to this design as the “In-track” APLs. Rather than just “ranging” off of an APL, additional carrier-phase measurements are made from APLs located at both runway ends [10]. The incorporation of this APL data in the position solution is expected to increase the vertical accuracy by a factor of 2. Stanford is currently flight testing this concept as well as a real-time integrity method that is similar to the RTCA method. A large-scale flight test on an FAA Boeing 727 will take place subsequently.

4. LAAS PLANS

FAA plans for future development of LAAS are very much dependent upon budgetary considerations. A life-cycle-cost estimate and cost benefit analysis for LAAS were completed in February of 1996, indicating that development and a modest deployment of LAAS systems would be cost justified. On that basis, the FAA decided to proceed with system specification and cooperation with industry on avionics standards.

The development of LAAS by the US Federal Aviation Administration has begun in earnest this past year. The FAA has reviewed the basic principles for a LAAS architecture with its industry and academia counterparts, and arrived at architecture conclusions and recommendations. These are currently being modified and amplified through RTCA Special Committee 159 (SC-159), and will be the basis for further system demonstration and validation, and eventual system specification. Most recently, the FAA presented the LAAS architecture to the International Civil Aviation Organization’s (ICAO) Global Navigation Satellite System Panel (GNSSP). Additionally, the FAA drafted and presented Standards and Recommended Practices (SARPS) for the basic LAAS and for the VHF data broadcast element of the architecture. These SARPS will be considered under the terms of GNSSP’s GBAS and Navigation Augmentation Broadcast System (NABS). FAA goals are for these SARPS to be accepted by GNSSP, and validated for ICAO acceptance and use. International acceptance of LAAS via the ICAO SARPS process will greatly benefit international aviation markets, particularly where terrestrial navigation aids are few or nonexistent.

Post-1998 LAAS work will focus on any needed further specification and MOPS validation. This will require a complete prototype that can be tested against requirements. Modifications to the specification and MOPS will then be made, as necessary. Simultaneously, the FAA will sponsor LAAS advanced research and development to ensure that LAAS definition keeps abreast of technical developments. Hopefully, the LAAS that is defined, specified, and tested will prove its merit and spur demand for acquisition and fielding.

5. SUMMARY

The paper indicates that the FAA is conducting a focused LAAS program that is already far along in architecture development and proof of concept. Required navigation performance requirements have been identified, large-scale flight testing has indicated that Category III autoland accuracy is attainable by a code-based Ground Based Augmentation System (GBAS), and an architecture that is interoperable for all categories of approach is maturing. A schedule for specification development, minimum operational performance standards (MOPS), standards and recommended practices (SARPS), and prototyping has been established. These activities make it possible to procure and implement a public use GBAS by the beginning of 2002.

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